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Review

The Evolution of Hunting Strategies in Tyrannosaurus rex: Analyzing Bite Force and Predatory Behavior

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Abstract: This literature review aims to gain a deeper understanding of the anatomy behind the jaw strength of *Tyrannosaurus rex* and analyze how these features contribute to its predatory behavior. This review will examine various studies and fossil excavations, exploring ideas such as the bite force of *T. rex* and its variations across different life stages. This will be obtained from numerous biomechanical models of both juvenile and adult *Tyrannosaurus rex*, as well as reference animals and dinosaurs for comparison. To provide additional information behind *T. rex*'s hunting techniques, we will also discuss the fauna of herbivorous dinosaurs that were part of *T. rex*'s diet. Furthermore, we will explore how mandibular stress concentration can vary between ages, a crucial topic in determining what *T. rex* could consume at certain stages of its life. Finally, we obtain a well-evidenced analysis of the various aspects of *Tyrannosaurus rex*'s hunting strategies throughout its lifetime.

The Evolution of Hunting Strategies in Tyrannosaurus rex: Analyzing Bite Force and Predatory Behavior

Tyrannosaurus rex is widely regarded as the most well-known carnivorous dinosaur to have ever walked planet Earth. Although it wielded two small arms, Tyrannosaurus rex also displayed a powerful tail, binocular vision, and a massive skull. Hence, this dinosaur from the Late Cretaceous was positioned at the top of its ecosystem's food web, its prey consisting of many dinosaurs that other carnivorous theropods might not have been able to typically hunt. With territories spanning across what is now Northern America, its habitat mostly consisted of forested river valleys and coastal plains.

Many previous studies have analyzed widely debated ideas regarding whether *T. rex* lived as a scavenger, a hunter, or both. This study is solely regarding its hunting techniques and ability to capture prey. *T. rex,* compared to other tyrannosaurids, exhibited varied bite forces and differing mandibular structures suited to specific tasks. Additionally, different tyrannosaurids exhibited distinct musculature that was suited best for their size and overall predatory behavior (Snively & Russell, 2007). Functions of the jaw for tyrannosaurids ranged from crushing bone, tearing flesh, puncturing and suffocating prey, to latching onto prey.

The purpose of this literature review is to gain a deeper understanding of the anatomy behind the jaw strength of *Tyrannosaurus rex* and analyze how features like this contribute to the predatory aspect of its behavior. I will delve into the bite force of *T. rex* and its variations across members of different ages. I will then discuss *T. rex*'s predatory tendencies and the fauna of dinosaurs that it typically preyed on. Then, I will end with a conclusion regarding the types of creatures that *T. rex* hunted at certain stages of its life, based on the in-depth understanding of its bite force.

The Jaw Strength of Tyrannosaurus Rex

Jaw strength is a strong indicator of diet. Herbivores tend to have smaller bite forces, as their plant-based diet does not usually require intense jaw movements and control. However, carnivorous jaws are known to have incredibly large bite forces, as this characteristic is crucial in hunting

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behaviors such as latching on to prey, tearing away flesh, and crushing bone. Consequently, carnivores, especially theropods of the Mesozoic Era, would have a diet consisting of other dinosaurs.

Furthermore, depending on their predatory behaviors, bite force can vary between carnivorous theropods. A smaller and lighter theropod, such as *Albertosaurus*, would have a weaker jaw strength compared to that of *T. rex*. *Albertosaurus* typically relies on its speed and teeth designed to slice through flesh, meaning that jaw strength would not be a major factor in a successful hunt. On the other hand, *T. rex*'s primary means of attack are its immense head, containing powerful mandibles and a set of teeth designed to crush bone (Carr & Williamson, 2004). A study conducted by Hutchinson & Garcia (2002) confirms this, as it was determined that T. rex likely did not have the musculature necessary for quick speeds.

Numerous studies have examined the biomechanics of jaw strength in *Tyrannosaurus rex* juveniles and adults. A study carried out by Rowe & Snively (2021) modeled mandibular stresses in various tyrannosaurids, among them a *T. rex* adult and juvenile model. The experiment used the finite element analysis (FEA) mathematical tool to model the biomechanical stress in the tyrannosaurid models. It also refined all the models to be more biologically accurate, such as remeshing unrealistically sharp boundaries and ensuring that the triangles used in the model are best representative of a tyrannosaurid jaw. Reconstructions of jaw muscles were also imported into the model, and through scaling factors such as the subtemporal fenestra method (Sakamoto, 2006), estimated stresses were determined for the tyrannosaurid models. These stresses were compared to von Mises stress to best predict failure due to ductile fracture. The results were that on a stress distribution model, *T. rex* juveniles experienced a majority of the mandibular stress in the posterior region of the mandible. Meanwhile, *T. rex* adult individuals experienced the most stress in the mid-mandibular region, suggesting a difference in diet between juveniles and adults. Additionally, when considering safety factors, the *T. rex* adult model can withstand significantly more stress compared to the *T. rex* juvenile model, meaning that as the *Tyrannosaurus rex* progresses through its life, its mandible will undergo much ontogenetic growth. This results in *Tyrannosaurus rex*'s increased bite force and ability to perform better without risking mandibular injury, which was also observed in a study conducted by Therrian et al. (2005).

Another study conducted by Bates & Falkingham (2012) estimated the bite force of both an adult and juvenile *Tyrannosaurus rex* through modeling. A Z&F 5600i laser scanner was used to digitize various models, including an adult and juvenile *T. rex*. GaitSym was used to investigate the bite forces for each of the models. Other features were also added to the models to make them as realistic to the organisms, such as musculature, muscle mass, bite velocity, and bite angle (20°) that are implemented during applying force on a source prey. The results were that at the posterior region of the mandible, the juvenile *T. rex* had an estimated bite force of 2565-4012 N, while the adult *T. rex* had an estimated bite force of 35640 - 57158 N. This further demonstrates the various bite forces that an individual *T. rex* may develop throughout its lifetime. In addition, when comparing the anatomical structures of a juvenile and adult *T. rex*, the juvenile wields a narrower, elongated snout, while the adult has a wider, larger rostrum capable of delivering significantly stronger bite forces. These findings corroborate those of Snively & Henderson (2007), as their results showed that rapid accelerations and torque generated by the neck are supported in adult *T. rex*, with several strong cervical muscles that allow for these actions.

Jaw strength is a key aspect of *Tyrannosaurus rex* that develops over its lifetime. As Rowe & Snively (2021) mentioned, mandibular stress in a *T. rex* shifts from posterior during adolescence to mid-mandibular during adulthood. Furthermore, as an adult, *T. rex* wields biomechanical properties that enable its jaw to withstand larger bite forces without compromising stability and risking injury. According to Bates & Falkingham, juveniles can have bite forces of 2565-4012 N due to their narrower, elongated rostrums, while adults can have bite forces of 35640 - 57158 N due to their wider, larger rostrum and mandible. Therefore, jaw strength develops and increases over *Tyrannosaurus rex*'s lifetime, and through analysis of mandibular stress distributions, it is a strong indicator of its diet at different stages of life.

Predatory Tendencies of Tyrannosaurus Rex

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As one of the top predators of its region, *Tyrannosaurus rex* hunted a variety of prey. However, there are numerous theories behind how *T. rex* achieved this, such as ambush, pursuit, and social hunting. Its muscular legs could be used for quick bursts of speed and energy, meaning that it could either be an ambush or pursuit hunter. Furthermore, there exist several *Tyrannosaurus rex* fossils found close to each other at several excavation sites, suggesting the possibility that *T. rex* hunted in social groups. However, not many studies have been conducted that relate to investigating the possibilities of *T. rex* being an ambush or social predator. Despite these hurdles, there is a study that can provide a reasonable insight into the predatory behavior of *Tyrannosaurus rex*.

An experiment conducted by Depalma et al. (2013) analyzed a traumatically infused hadrosaur fossil that partially encompassed a *Tyrannosaurus rex* tooth crown, found in South Dakota's Hell Creek Formation. Some evidence of an unsuccessful *T. rex* attack is dental penetration and osteomyelitis in the bone region. In addition, the rugose structures observed on the hadrosaur fossil were consistent with modern-day comparisons. This is because reptilian bone is known to take longer healing times, and the same occurred with the hadrosaur specimen. Furthermore, the inflicted area followed the signs and observations of a wound that was not lethal. The researchers found that the hadrosaur likely survived for years after the incident, with minimal, if any, long-term health concerns caused by the *Tyrannosaurus rex*. The other piece of evidence obtained from the analysis was that the attack matched conditions seen in modern-day hunting techniques typically used by big cats, such as lions. These attacks involve initial grasping of the hindquarters, gaining control of it. Once in control, the lion will proceed with its attempt to kill the prey, clawing and biting it. A similar predatory technique could be applied to *Tyrannosaurus rex*. It used its large skull and strong jaw in an attempt to immobilize the hadrosaur. However, in this scenario, the hadrosaur managed to flee the situation, escaping with its life. This study is a strong indicator that *T. rex* engaged in pursuit predation, chasing after its prey in short bursts of speed and engaging.

Although we currently cannot determine if *Tyrannosaurus rex* used other hunting techniques such as ambush predation and social groups, we have a substantial idea of one method that *T. rex* used: pursuit predation. As observed by Depalma et al. (2013), *T. rex* would quickly chase after its prey and attack near the mid-caudal section of its prey, similar to modern big cats. Therefore, pursuit predation is a key aspect of *Tyrannosaurus rex*'s hunting behavior, providing a crucial insight into its diet and lifestyle.

Prey of Tyrannosaurus Rex

Tyrannosaurus rex would have a large variety of dinosaurs that it could prey on due to its immense size and strength. However, in this review I will discuss North American dinosaurs that are part of *T. rex*'s central diet, or prey that it usually hunts. This would provide valuable insight into how certain prey items could be part of *T. rex*'s central diet at some stages of its life but not others, allowing us to gain a deeper understanding of the relationship between *T. rex*'s jaw strength and its diet throughout its lifetime.

Various North American excavations have shown juvenile *T. rex* preying on and hunting herbivorous dinosaurs such as *Triceratops*, *Edmontosaurus*, *Thescelosaurus*, and *Hypacrosaurus*. Other areas of excavation sites across North America have shown adult *T. rex* attacking dinosaurs like *Triceratops*, *Edmontosaurus*, *Ankylosaurus*, and other hadrosaurs and ceratopsians. Upon analysis of various fossil evidence, there are many similarities between juvenile and adult *Tyrannosaurus rex* regarding the prey that they hunted. These excavation results are similar to those of Carbone et al. (2010), as their study determined that T. rex most likely competed with other large carnivorous theropods in the region for accessibility to large vertebrates. This mostly consisted of herbivorous dinosaurs like *Triceratops* and *Edmontosaurus*, as shown above.

However, it is important to note the circumstances behind the hunting behaviors of *T. rex* at different stages of life. As previously mentioned by Bates & Falkingham, juvenile *T. rex* had an estimated bite force of 2565-4012 N, while adult *T. rex* had an estimated bite force of 35640 - 57158 N. Additionally, it was determined that adult *T. rex* have a much greater capability of withstanding intense and powerful jaw movements through various characteristics such as mandible size, cranial structure relative to point of pressure, and better safety factors. Consequently, adult *Tyrannosaurus rex* would be able to prey on a larger and armored dinosaur on a more regular basis compared to a juvenile, as it would be better capable of crushing through the various exterior layers of the dinosaur and more likely to have a successful hunt. On the other hand, the juvenile *Tyrannosaurus rex* would mostly hunt smaller prey with relatively less body armor than other dinosaurs. It would occasionally prey on larger and more armored dinosaurs, as it was still of relatively average size compared to them. Still, based on previously gathered evidence, it is unlikely that they performed these hunts on a daily basis.

Conclusions

Limitations on Existing Research

Though numerous studies have investigated many aspects of the *Tyrannosaurus rex* mandibular structure, such as musculature and stress distribution, much more research is needed to determine the hunting behaviors of *T. rex* at different stages of its lifetime. *T. rex* could have employed more of an ambush or social group method of hunting, rather than solely pursuit hunting as described by Depalma et al. (2013). As a result, scientists cannot depict how *T. rex* engaged in its predation. In addition, models of tyrannosaurids cannot fully represent the corresponding structure, as certain aspects may differ from the specimen, such as musculature, tendons, and ligaments. Therefore, there are numerous limitations in understanding the entire hunting strategy and technique used by *Tyrannosaurus rex* at certain life stages.

Takeaway

Tyrannosaurus rex engaged in pursuit predation of its prey, using quick, short bursts of speed and attacking its target. One such strategy is using its large skull and strong jaw to immobilize the prey in the mid-caudal region, a method also employed in modern-day big cats. Juvenile *T. rex* typically hunted smaller, less armored herbivorous dinosaurs, as models estimate them to have a bite force of 2565-4012 N, Meanwhile, adult *T. rex* tended to hunt larger dinosaurs, including armored ones like *Ankylosaurus*, and had an estimated bite force of 35640 - 57158 N. This corroborates with other studies that discovered that upon biting, juvenile *T. rex* had most of the stress concentrated on the posterior region of its mandible, due to its narrower snout and less developed mandible. In contrast, adult *T. rex* had the most stress on the mid-mandibular region, due to its wider rostrum and more developed mandible. Furthermore, the adult *T. rex* wields numerous safety factors that prevent mandibular injury, enabling it to have a stronger bite force. In conclusion, understanding *Tyrannosaurus rex*'s hunting behavior is mostly up to speculation. However, using existing studies and evidence, we can determine that bite force and other jaw characteristics of *T. rex* develop through ontogenetic growth that allows it to have progressively increased jaw strength, as well as the ability to engage in pursuit hunting against larger, armored herbivorous dinosaurs.

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